Working Paper

Working Paper 63

SOME PERIGLACIAL MASS MOVEMENTS IN FINE GRAINED UNCONSOLIDATED MATERIAL IN SUB ARCTIC CANADA

James R. Petch

Department of Geography

University of Leeds

Working Paper 63

SOME PERIGLACIAL MASS MOVEMENTS IN FINE GRAINED UNCONSOLIDATED MATERIAL IN SUB ARCTIC CANADA

James R. Petch

Department of Geography
University of Leeds

June 1974

ABSTRACT

Observations of mass movement processes on the north east facing slope of a mine spoil heap in sub-arctic Canada are presented. The influence of certain meteorological events is shown. The forms of movements and deposits are described in chronological order and the form and process of slope development are discussed. The complexity of the development is stressed.

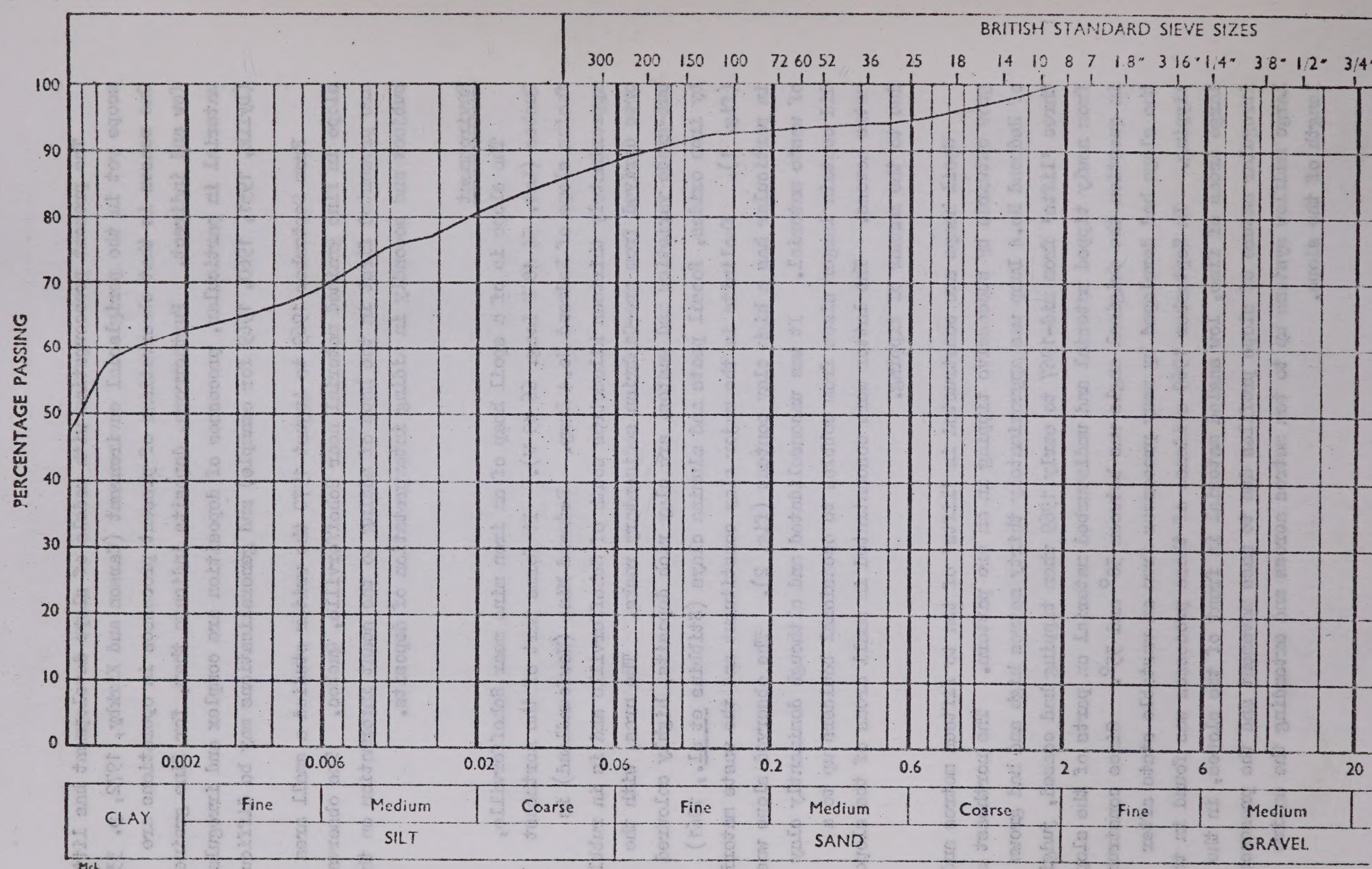
The present preoccupation with models of slope development has little scope yet in the periglacial environment (Carson and Kirkby, 1972, p. 337). One reason is that observations of present processes in operations are few and indirect. Furthermore, deposits indicate that, for fine grained material in particular, processes of deposition are complex and irregular (Dylik, 1951, 1960, 1969 for example) and generalisations may be difficult.

From September 1969 to August 1970 the writer studied a small area of slope in fine grained material near Schefferville, Quebec. The observations are presented first in the hope of adding to the scant information on the subject and secondly in aiding interpretation of deposits.

Environment

The slope is of a spoil heap of an iron mine near Schefferville, Quebec (Lat. 54 48 N Long. 66 49 W). It forms part of the northeast facing slope of Redmond No.4 Dump. Redmond Mine (Newfoundland) is approximately thirteen kilometres south of Schefferville and is in rubble ores derived from pre-Cambrian sedimentary rocks. The ores, with the sub-grade varieties and wastes, are clay rich deposits, highly coloured by iron oxides, fossil peats and alumina clays (Stibbins et al., 1961) (fig. 1). Kaolinite is the major clay constituent and the waste material in particular has a high clay content (fig. 2). The observed slope was of waste material. It was unconsolidated and although dominantly clay did contain larger sizes from cobbles to occasional boulders up to a metre across. The latter were concentrated in small areas of the slope due to the manner of tipping.

Spoil heaps are constructed in 'lifts' of ten to fifteen metres and grow outwards by successive tipping in an arc pattern. The northeast slope of Redmond No.4 Dump was approximately thirty metres high and had grown in three 'lifts' from mid-1967 to early 1969 when tipping had ceased, judging from newly tipped material and undisturbed material on parts of the slope in question the original angle was between 30° and 35°. Since construction the slope had developed by many processes from an unstable state after tipping. In September 1969 evidence of these processes was found in the large areas of fine, low angled material in front of the slopes, in the irregular nature of slope profiles due to mass movement and the presence of large mudflow systems up to ten metres across and extending the entire length of the slope.



BRITISH STANDARD SIEVE SIZES
300 200 150 100 72 60 52 36 25 18 14 10 8 7 1.8" 3 16" 1/4" 3 8" 1/2" 3/4"
PERCENTAGE PASSING
100 90 80 70 60 50 40 30 20 10 0
0.002 0.006 0.02 0.06 0.2 0.6 2 6 20
CLAY
Fine
Medium
Coarse
SILT
Fine
Medium
Coarse
SAND
Fine
Medium
GRAVEL
McL

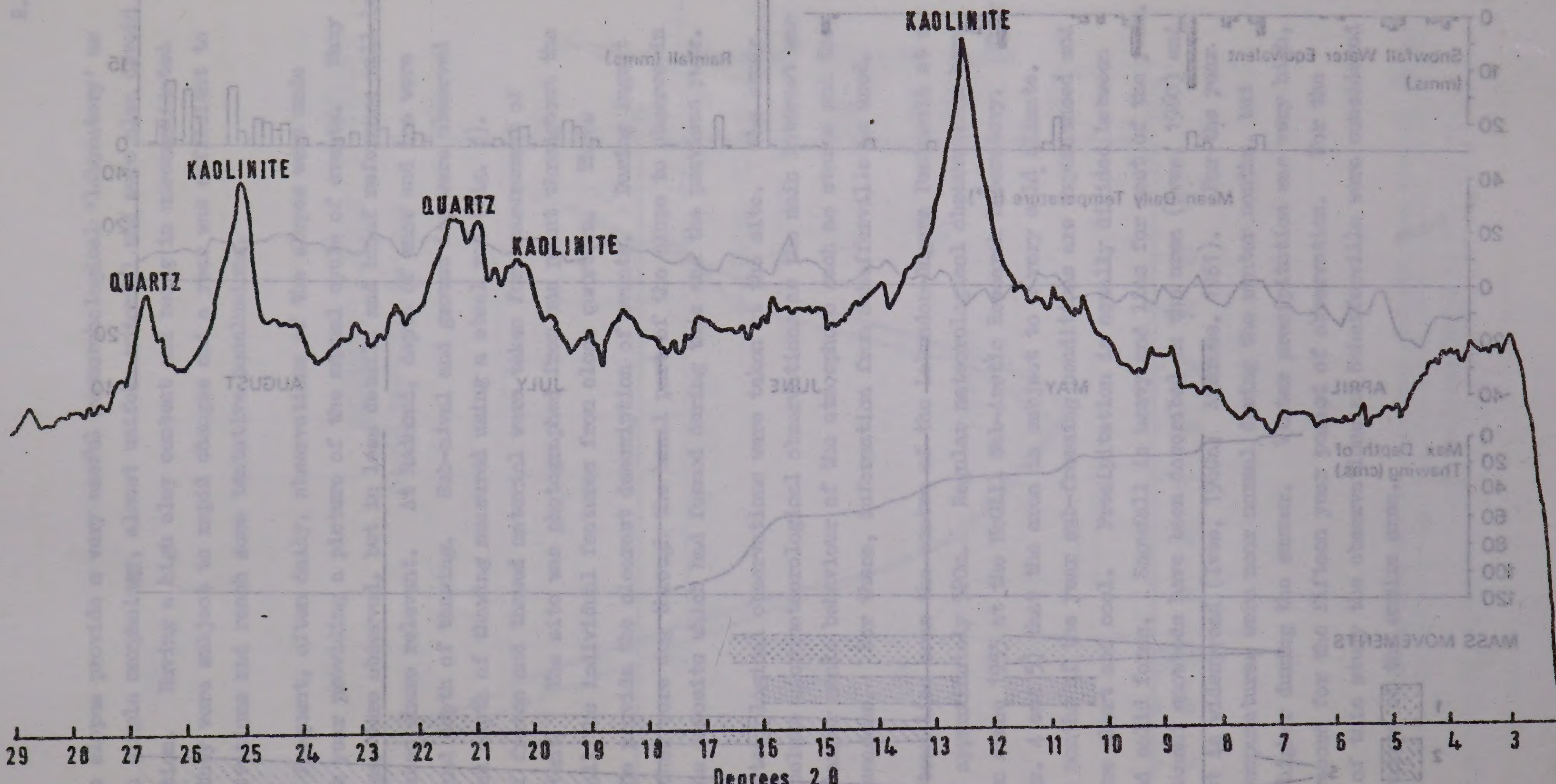
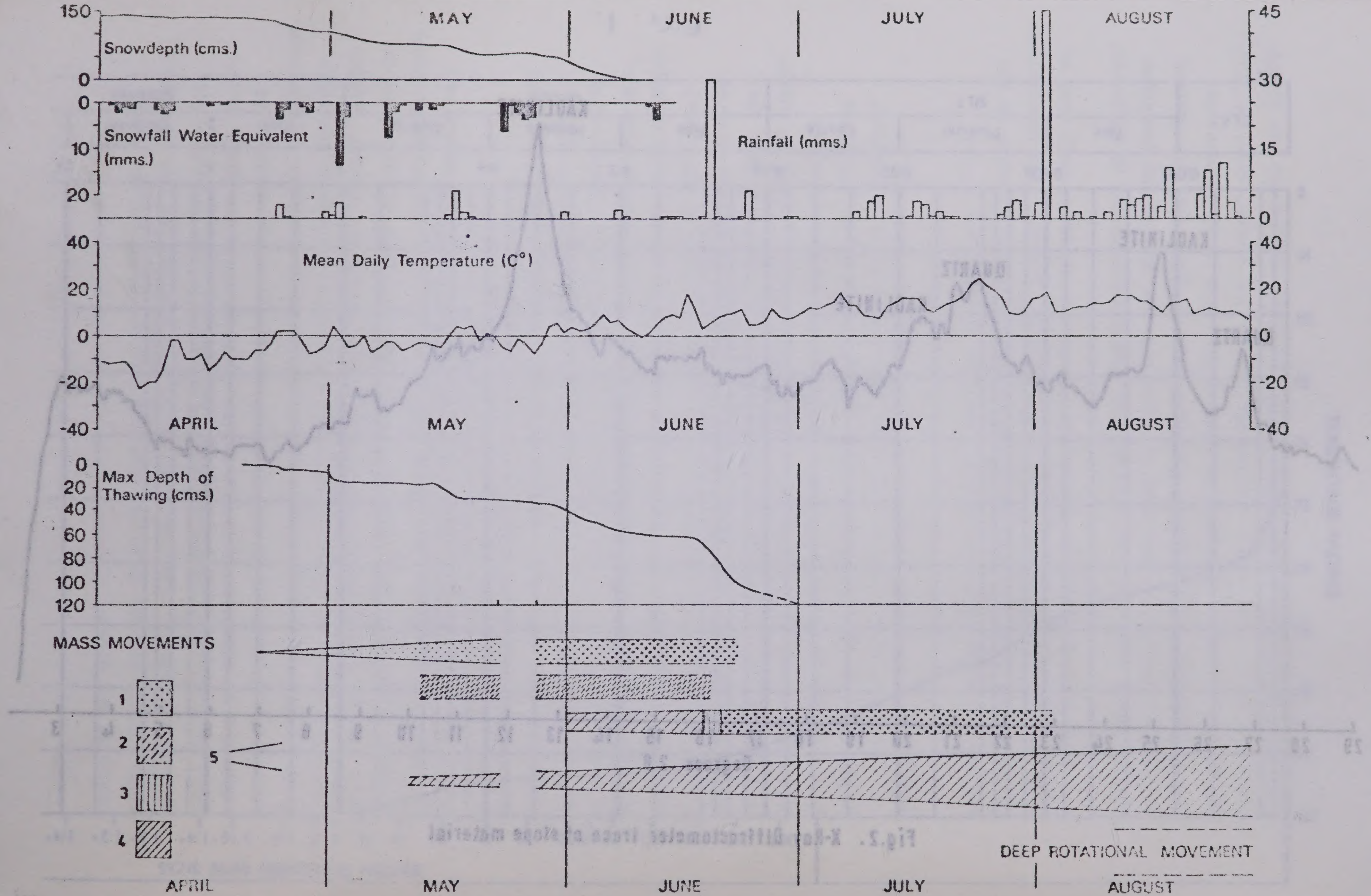


Fig.2. X-Ray Diffractometer trace of slope material



Snowdepth (cms.)
Snowfall Water Equivalent (mms.)
Rainfall (mms.)
Mean Daily Temperature (C°)
Max Depth of Thawing (cms.)
MASS MOVEMENTS
DEEP ROTATIONAL MOVEMENT
APRIL
MAY
JUNE
JULY
AUGUST

FIG. 3

These slopes provide a very useful geomorphological 'laboratory' as they had a simple morphology, almost uniform material and were also devoid of vegetation. Having a high clay content and being in unconsolidated material they were subject to rapid changes and a year was sufficient to make observations and reach some tentative conclusions.

Very frequent, often daily, observations of the slopes were made during the year providing a picture of the annual cycle of events. Many other slopes were observed, but in less detail, and brief reference will be made to these where relevant. At Redmond, depth of snow and ice were observed and depth of thawing. Sub-nival and ground ice were observed in pits and depth of thawing measured using a steel rod (fig. 3). Samples of frozen and thawed material were taken for measurement of water content. The site was photographed from one point throughout the year and all the individual features from close quarters. These photographs provide the clearest description of events. During August 1970 trenches were dug through the basal part of the slope to observe in section the deposits which had formed during this and the previous year.

No meteorological observations were taken at the site. The study did not include micrometeorological observations as the main interest was with the larger scale behaviour of the atmosphere such as storms and the changing seasons. For these, information from Schefferville is used.

The town lies near the centre of the Labrador-Ungava Peninsula at a height of approximately 520m. Regular meteorological observations have been taken since 1955 at the McGill Sub-Arctic Research Laboratory. They show (figs. 4 and 5) that the area is subject to a very cold climate. For eight months of the year sub-freezing conditions are experienced and summers are short and cool. Precipitation is equally divided between liquid and solid forms. Snowfall is heavy and lies for most of the year. Semi-permanent snowbeds have been described in the area (Ives, 1960) and permafrost is widespread (Ives, 1960a; Andrews, 1961). For the year 1969-70 temperatures were near normal during the winter months, but slightly higher during the summer. Winter precipitation was very high, being a record for the fifteen year period of observation. For the purposes of this study the observations at Schefferville were considered representative of the entire area.

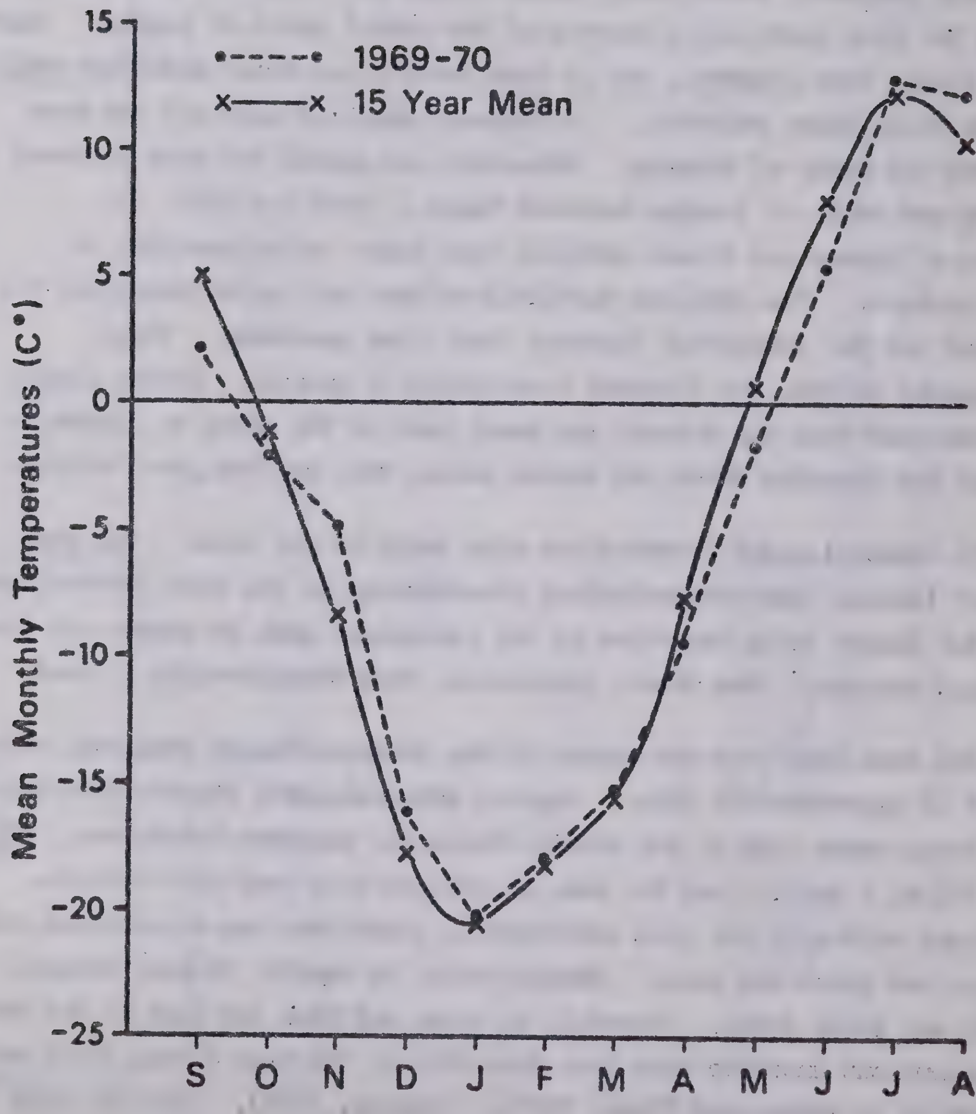


Fig. 4. 15 year mean monthly temperatures and mean monthly temperatures for 1969-70 at Schefferville, Que.

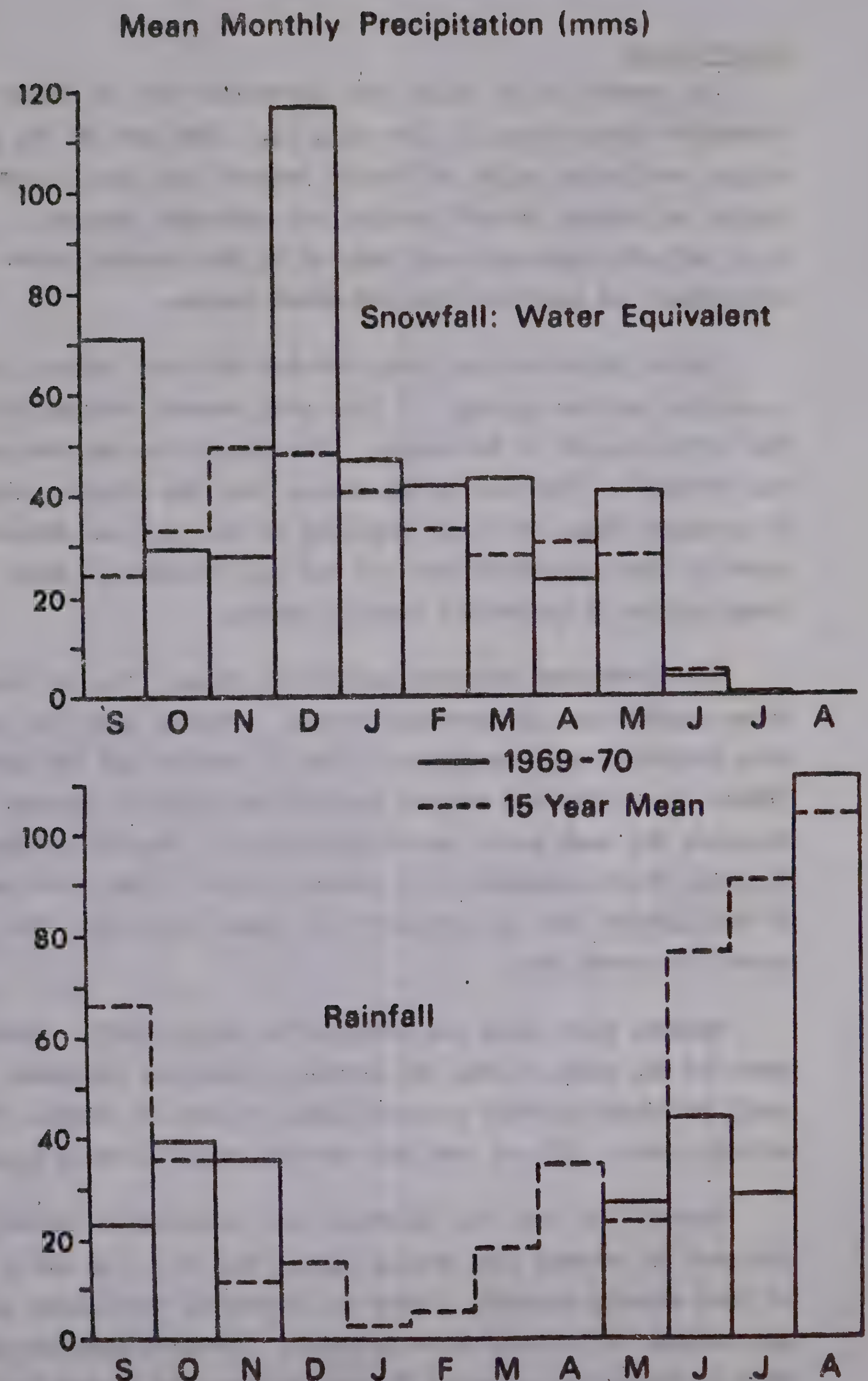


Fig. 5. 15 year mean monthly precipitation and mean monthly precipitation for 1969-70 at Schefferville, Que. Snowfall as water euivalent.

Observations

The events on the slope from September 1969 to August 1970 are described chronologically (see fig. 3). For most of the year the slopes are frozen solid and buried beneath more than a metre of snow. Spring and summer brought complex and extensive changes. These were in a definite succession and related to the changing state of the atmosphere and specific meteorological events.

During September and early October 1969 the Redmond site supported a complex mudflow system. A flow with several stepped lobes extended the entire length of the slope. The front lobe was ten metres wide and had extended a distance of two metres from the original slope foot. It overrode fine, low angle deposits of the previous summer. Other parts of the slope were very wet and had evidence of rapid creep in the large number of horizontal tension cracks.

In mid-October freezing conditions began; the top layer of material froze rapidly and all movement ceased. Before snow had accumulated in late October a semi-continuous cover of surface ice had developed (Photo 1). This was several centimetres thick in places. During November the snow cover became continuous. Ground ice grew and the freezing front extended to an unknown depth. From November until April it was assumed that no movement took place apart from that caused by growth of ground ice.

Maximum snow cover was attained in early April. Even on the steeper parts of the slope nearly two metres of snow was recorded. However, a few, small prominent patches remained free of snow all winter, but they were solidly frozen without even the surface material being loose (Photo 2).

Beneath the snow the thickness and structure of ground ice was observed in several pits during March (fig. 6). In all a similar section of four clearly separate layers was observed, containing different proportions of ice and slope material. Their separateness was demonstrated when meltwater was observed flowing between the layers in spring. The top layer of ice or hoar was derived from the snowpack and is a well recorded feature, but the bottom three were all ground ice. The lowest extended an unknown distance into the slope with ice content decreasing downwards from 45% at the top to under 20% at a depth of 25 cms. The formation of the middle layers with ice contents of 65-75% and 85-90% is not understood, but they were clearly separate and had distinct ice contents.


PHOTO 1

PHOTO 2

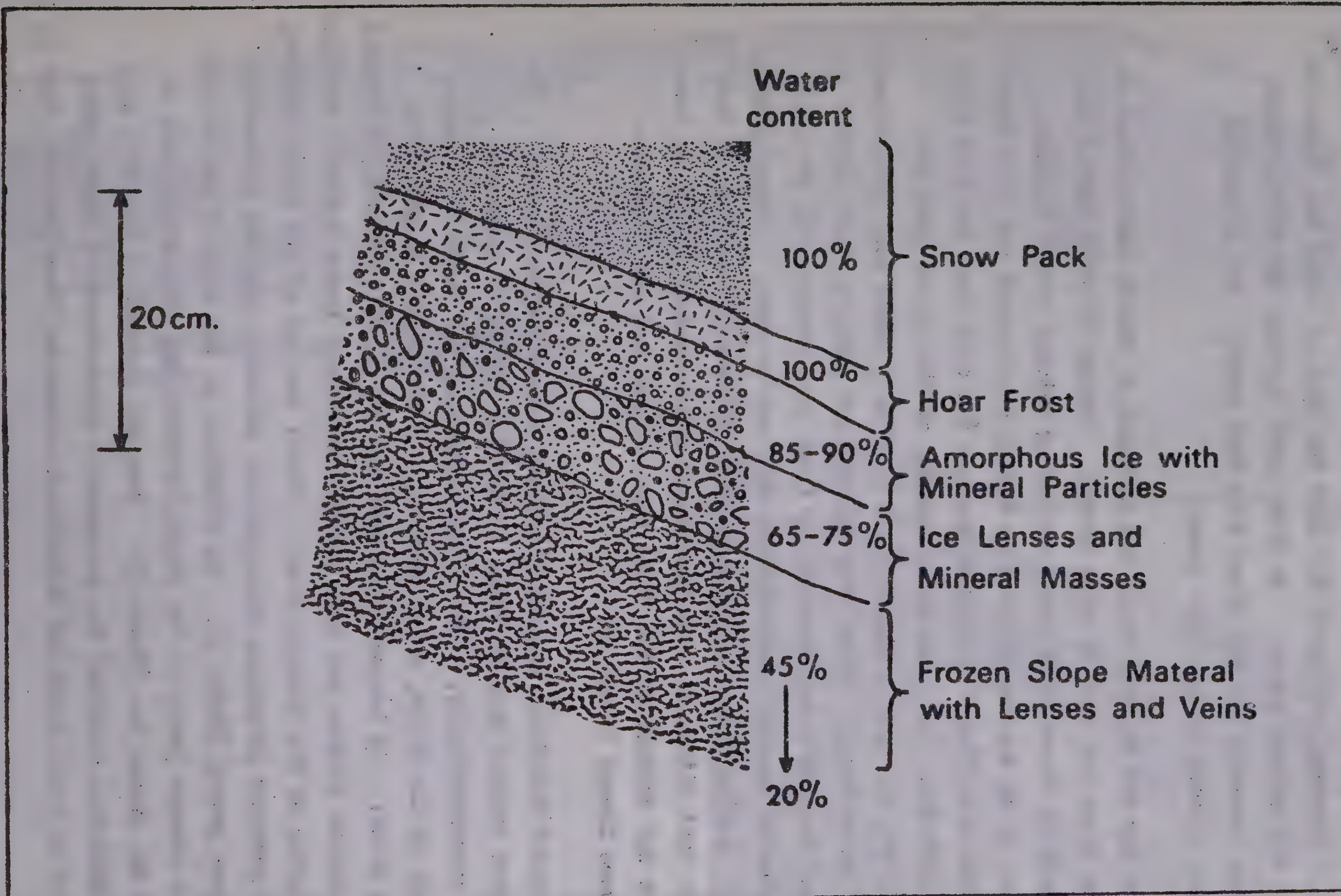



Fig. 6. Diagrammatic section through base of snowpack and slope surface during late winter.

Towards the end of April the snowpack began to diminish, and bare areas increased rapidly in size. There had been some small rain showers, occasional periods with temperatures above freezing and wet snow during the month. However, not until the last ten days of April was there any thawing of the exposed areas. On 20th April daytime air temperatures stayed above freezing for the first time that year. The immediate response was thawing of the bare areas.

By 4th May the thawing front had advanced to twenty centimetres on areas where there had been no snow cover. Layers of heavy ground ice began to melt in these small areas producing intense runoff locally. Small rills, up to ten centimetres in width, development and from these oversaturated soil flowed in narrow tongues (< 2 cms) over the snow (fig. 3, Mass Movement Type 1). The water content of the frozen soil was between 35% and 55% with a liquid limit of 35%. Hence soil disintegrated and flowed on melting. Water from melting ice added to that already in the soil and locally water contents in flows were measured up to 120%. Flowing material rapidly lost moisture and came to rest. Material which had started flowing with a water content of 50% would lose much of this and come to rest within an hour reaching a water content of 25% or less. Where water was channelled the flows would remain wet and extensive deposits were formed (Photo 5).

Subsequent rainfalls brought immediate and extensive changes. The depth of snow dropped rapidly (fig. 3) and the volume of meltwater increased correspondingly. The latter increased the depth of thawing, particularly in the rills, which grew rapidly and exuded larger lobes up to 10cm thick. As larger rills grew and the depth of thawing increased the lobes became thicker and incorporated occasional larger material released by the progress of the thawing front. Until the end of May these shallow, rapid mass movement processes developed and extended from the increasing areas of bare ground (Photo 3). In addition, at the edge of the melting snowpack on steeper parts of the slope, material was frequently seen to slump over the ground ice (Photo 4). Thus the retreat of the snow in a downslope direction involved the progressive disturbance of large areas of the slope in small slips and rotational movements (Mass Movement Type 2, fig. 3).

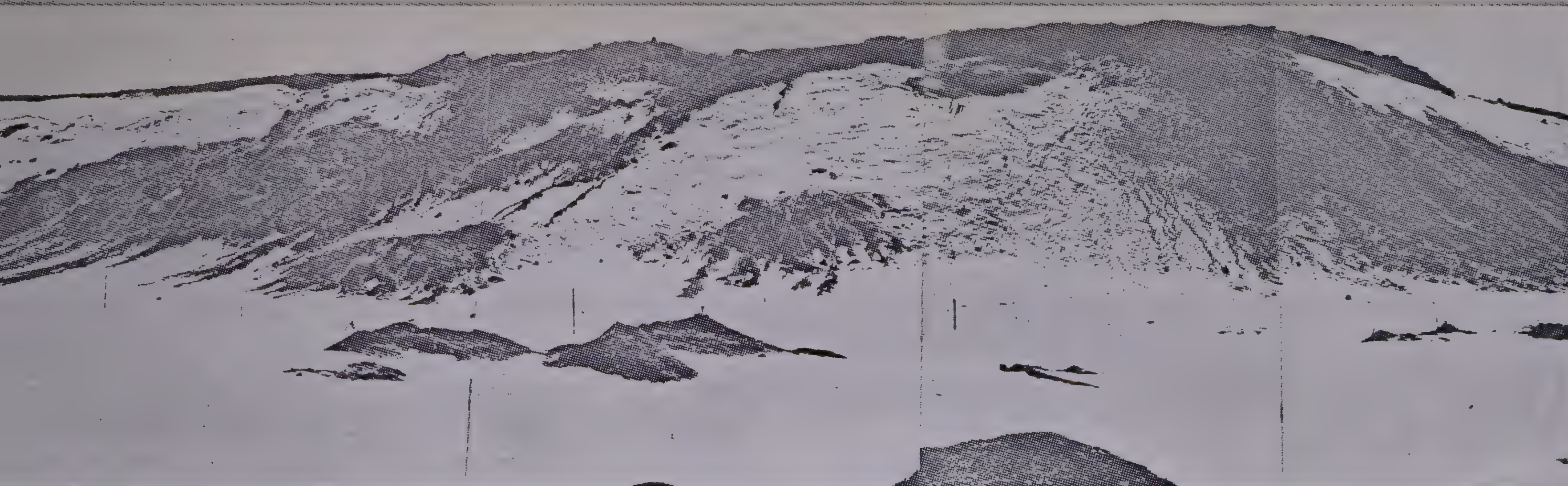


PHOTO 3

PHOTO 4

PHOTO 5

PHOTO 6

There was a cessation of these processes from 23rd May to 27th May when daytime temperatures fell below freezing and snow fell. The surface of the slope froze to a depth of two to five centimetres and all movement ceased. Warm weather and rain quickly erased the effects of this short cold spell and melting ground ice continued to feed thin mudflows, depositing a thin veneer of tongues of fine material over the lower parts of the slope.

On 18th June three centimetres of rain fell in association with the first intense depression to cross the Labrador Peninsula. On the following day occurred the second major series of events on the slope. A complex series of failures developed rapidly and simultaneously (Photo 5)(Mass Movement Type 3). By this date thawing had advanced to depths between thirty and sixty centimetres over the entire slope and most of the snow had disappeared.

Drainage was prevented by the frozen front and failures had slip planes on the frozen sub-surface. They started as blocks of material breaking away and sliding over the frozen plane. These blocks then disintegrated and flowed further downslope (Photo 6). The form of the resulting deposits varied greatly. Where material was deposited on snow or on drier parts of the slope distinctly hummocky forms were produced. Material which remained wet because of a good water supply formed a thin veneer on the slope and at the base fans were laid down (Photos 5 and 10).

From late June there were few changes on the slope in spite of occasional heavy rain and persistent warm temperatures. Throughout July and August the slope was subject to creep processes (Mass Movement Type 4) which by late August had manifested themselves in a series of large cracks over the slope (Photo 7). Mass movement scars and rills had started to become obliterated. The large mudflow observed on the slope the previous year did not develop. However, there were indications from crack patterns of deep failure on the upper half of the slope. Freeze up commenced in September with no other changes.

Discussion

From these few observations several points emerge which have a bearing on the interpretation of deposits thought to have been laid down under periglacial conditions. They are necessarily tentative because of the short period of observation and the unusual nature of the slopes. However, the great similarity between the Redmond deposits and those described in the literature (see especially Dylik, 1969) and between the observed processes and those inferred prompts the writer to present these few points.

One particular feature which may not be typical of natural slopes is the layered formation of ground ice. The dump slopes provide very wet environments, devoid of vegetation and very exposed; conditions which promote good growth of ice. On natural slopes the annual formation of such masses of ice has not been recorded and the layering remains unexplained. The great growth of ice emphasised one process which may be of considerable importance in the geomorphological development of periglacial areas. This is the transportation by meltwater of material away from the slope. Growth of ice in intimate contact with the soil provides good conditions for the removal of material at thaw. Mass movement processes are generally considered to involve merely a redistribution of material on the slope (Dylik, 1969; Jahn, 1969).

The behaviour of the Redmond slope demonstrates clearly the influence of meteorological events on geomorphic processes in this environment. In particular the influence of rainfall and advected warm air are clearly demonstrated. The first small, shallow mass movements began in late April only with the advection of warm air and rain. Those areas (on all spoil heaps) which had been free of snow through the winter and had experienced many hours of intense sunshine, whatever their aspect, had remained solidly frozen. With the first advected warm air of spring, shallow mass movements were seen on many slopes irrespective of aspect or material.

Mass movements in mid-June were related to the first heavy rainfall of the summer. The timing of such movements depends on antecedent moisture conditions, the magnitude of the rainfall and the depth of thawing. Over a large part of the slope the balance of forces was changed after the 18th June rain. However, these large failures had less spectacular precursors and small failures continued throughout the summer exuding thin lobes of wet material. Creep processes were manifest throughout the season forming part of the whole complex series of events.

The continuous movement of material produced layers of deposits on the lower parts of the slope. That deposited from the melting snowpack with that from melting ground ice was very fine. Thin mudflows were deposited above. They became increasingly thicker during the summer (Photo 8) and incorporated some larger material and thus, as lobes were deposited irregularly, well stratified deposits were formed (Dylik, 1960).

PHOTO 7

PHOTO 8

PHOTO 9

PHOTO 10

Stratification was also promoted by the sorting effect of mudflows (Photo 9). The efficiency of sorting depends on the fluidity of lobes and successive lobes from one scar, which had different water contents, were easily separable (Photo 10).

Deposition was further complicated by reworking during melting of snow or ice. Many lobes and fans, particularly during the early summer, were deposited directly on snow and stratifications were destroyed or severely altered on melting. Fig. 7 illustrates two simplified examples. Thin flow deposits were generally regular in thickness. When laid down directly on the slope they adjusted to the surface topography. Those deposited on snow would produce a regular cover over the most irregular sub-nival surface (fig. 7.A), after melting. Dirty snow melts irregularly and therefore where successive deposits were laid down during melting the final product could be very complex (fig. 7.B).

From these few observations several points can be made about processes of periglacial mass movement and deposition which it is believed may apply to other slopes.

First, this work illustrates the importance of the first advected warm air and rain at the beginning of spring. In addition, erosional processes during late summer, when the thawing front had advanced to a considerable depth, were not directly related to the weather. Undoubtedly, more complex relations exist which demand observations over longer periods of time.

Second, the great importance of ground ice in influencing periglacial slope processes is indicated by most of the observations.

Third, the effectiveness of rapid mass movements in sorting material was seen clearly on several occasions.

Fourth, this work indicates that snow and ice are important in reworking deposits and complicating the relations of beds.

Finally, many different types of features and deposits were represented which occurred in succession and juxtaposted (fig. 3). It was impossible to fit these processes and forms into distinct categories. For movements from water flow to block slides there were no sensible divisions (Matthews and Petch, 1969).

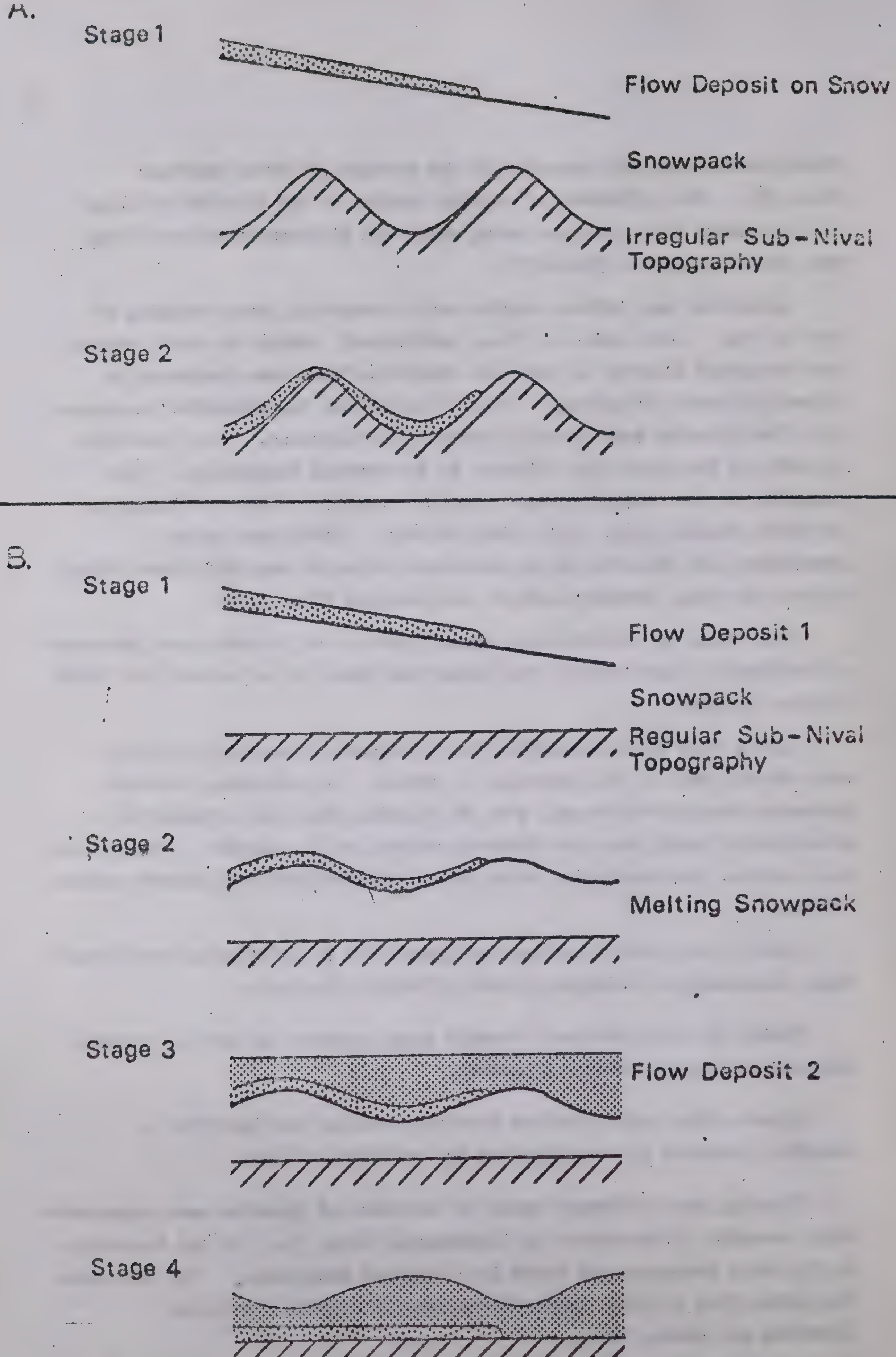


Fig. 7. Diagrammatic representation of the effect of melting snow on deposition. A, with uneven sub-nival surface; B, with successive deposition during melting.

The patterns of material movements at the site were very complex. Thin mudflows and sheets transported material mainly from the middle and upper parts of the slope to areas immediately downslope. Evacuation was from restricted areas to more extensive ones. During the early part of the year material moved from rills; during the later part from block movement scars. This process continued throughout most of the summer.

A second pattern of movement was linked to the melting of the snowpack. This was the successive slippage of material over melting ground ice at the edge of the pack where it was retreating in a downslope direction. It can be seen from photo 3 that the pack is generally retreating downslope and that the effects of this process were extensive. Material moved the order of thirty centimetres but also to a depth of the same order and had a rotational movement. The process continued for as long as the snowpack took to melt.

Rapid, block movements took place only once on this slope during the period of observation. They require a substantial and extensive thawing followed by a significant fall of rain or other supply of water. Large areas of the middle and upper slope were affected and the evacuated material deposited immediately downslope after disintegrating.

Creep processes were ubiquitous. Their effects increased during the year.

In general the mass movement processes caused a removal of material from large areas of the middle and upper slope and distributed it over the middle and lower slope. The snowpack acts as a very effective barrier to material transport because of the loss of momentum and water. As the deepest and longest lasting snow was at the base of the slope this meant that material was confined to the slope and generally not removed.

Conclusions

This work confirms the observations of Dylik and others that the majority of periglacial slope activity involves merely redistribution of material rather than evacuation from the site.

As regards the method of redistribution it is most important to stress that a succession of processes occur during the year and that to attribute the development of the slope to one set of processes can be erroneous (fig. 3). During the early part of the thaw only the first few millimetres of ground are free to move, infiltration is very low and

water is very available. A situation exists in which the responses to meteorological forces is extremely rapid and extensive. The effects of advected warm air and rain are paramount. Later in the season when the snow has melted, ground ice becomes dominant in influencing the rate of processes and the form of mass movements. Surface flow is reduced as infiltration increases and the response to rainfall events becomes less direct. Heavier rains are required to make a direct impact on the slope and the form of the response differs from the earlier movements being deeper and less fluid. The slope comes to respond like a more normal slope of temperate regions where the significant hydrological conditions are the rates of movement of water onto and out of the surface layers. Superimposed on these processes are several peculiar to cold environments due to the presence of snow and ice.

This small simple site illustrates clearly the complexity of form and process which can be experienced in one season. It indicates that to construct general models of slope development from the meagre evidence available may be dangerous.

References

Andrews, J.T. (1961) Permafrost in Southern Labrador-Ungava, Canadian Geogr., 3, 34-35, Toronto.

Carson, M.A. and Kirkby, M.J. (1972) Hillslope Form and Process, Cambridge University Press, 475pp.

Dylik, J. (1951) Some periglacial structures in Pleistocene Deposits of Middle Poland, Biul. Soc. Sci. Lett. Łodz., 3, 2.

_______ (1960) Rhythmically stratified slope deposits, Biuletyn Periyglacjalny, 8, 31-41, Łodz.

_______ (1969) Slope development under periglacial conditions in the Lodz region, Biuletyn Periyglacjalny, 18, 381-410, Łodz.

Ives, J.D. (1960) Semi-permanent snowbeds in central Labrador-Ungava, McGill Sub-Arctic Res. Paper, 9, 45-55, Montreal.

_______ (1960)a Permafrost in central Labrador-Ungava, J. of Glaciol., 3, 789, Cambridge.

Jahn, A. (1969) Some problems concerning slope development in the Sudets region, Biuletyn Periyglacjalny, 18, 331-348, Łodz.

Matthews, J.A. and Petch, J.R. (1969) Mass movement forms in a Welsh valley: an essay on morphological description, Horizon, 19, 46-65, London.

Stibbins, J.B., Blais, R.A. and Zajac, I.S. (1961) Origin of the soft iron ores of the Knob Lake region, Trans. Can. Inst. Mining Met., 54, 43-58, Ottawa.